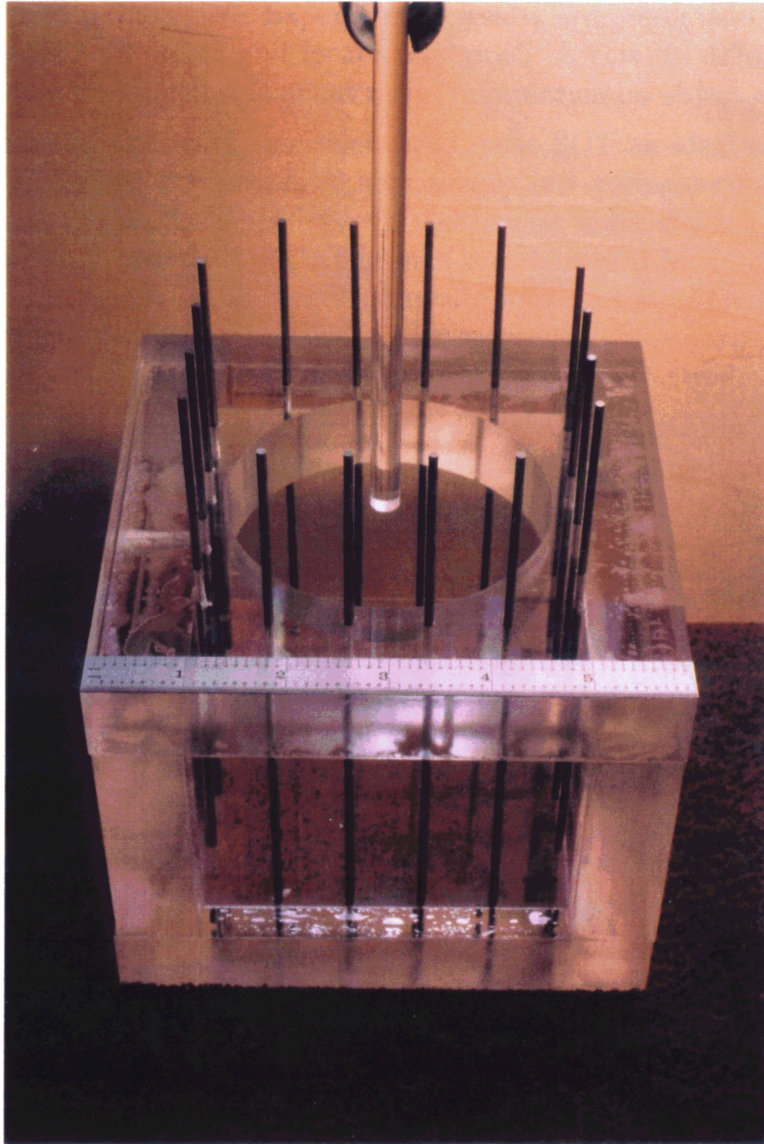


Surface Charge Tomography System

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Summary

Surface Charge Tomography (SCT) is a noninvasive technique for imaging electrical conductivity variations within a body. Just as x-ray (CAT) images density, magnetic resonance (MRI) images specific isotope density, and ultrasound images sound speed, SCT provides an image of a particular physical property of the material being tested. SCT provides new diagnostic information, which could prove invaluable in detecting certain types of defects and pathologies. Experimental results are presented that demonstrate the capability of SCT to detect and locate very small objects, to differentiate between neighboring objects, and to provide quantitative information on object size and location.

Cost, performance, and safety considerations make SCT an ideal candidate for use in routine diagnostic procedures. SCT uses a very low voltage, comparable to that associated with a common flashlight battery, and has far fewer clinical risks than either ionizing radiation employed in x-ray CAT or microwaves used in MRI. SCT is potentially very inexpensive because it requires measurements which are easily automated directly by computer, without complex transducer and measurement hardware. Its simplicity is reflected in the fact that the transducer is simply an array of electrodes.

SCT has potential applications in a variety of fields. Examples from biomedical imaging, nondestructive testing, on-line production measurements, and geophysical prospecting are discussed below.

Underlying Physics

SCT utilizes information from applied electric fields to image dielectric objects in an electrically conductive medium. A dielectric is a nonconductor, which can also be the source of an electric field, in that it can be polarized. Examples of dielectrics include oil, air, glass, plastic, and ceramic. Dielectrics are used as fill material for capacitors, since the polarizability of the dielectric affects the amount of charge that a capacitor can store. In an SCT system, it is the surface charge on the boundary of the dielectric which acts as a source and provides the information necessary for image reconstruction.

When a dielectric is placed in a conducting electric field, charge accumulates on its surface. The surface charge gives rise to a secondary electric field, causing the current to flow around the dielectric, which is a nonconductor. This secondary field can then be measured at a distance from the dielectric. There are several factors which influence the amplitude of the secondary field, including the size, shape and location of the dielectric and the orientation of the incident field.

The SCT system functions both to provide the primary electric field and to record the secondary field. Both the application and recording of the fields are done from the exterior of the object being imaged. This makes the method noninvasive, since the insertion of devices into the object is not required. As in other tomographic imaging systems, the incident field is varied so as to illuminate the object from a variety of angles, thereby collecting as complete a data set as possible.

Experimental System

The SCT system can be logically divided into the following components: transducer; drive signal and switching; data acquisition; data processing; and display. All of these functions were performed using a generic ISA-Bus computer, with commercially available plug-in A/D and switching cards. Data processing involved the implementation of both noise-reduction and image-resconstruction algorithms, developed specifically for SCT by the author.

The transducer (see cover page) consisted of a fluid-filled test cell with sixteen electrodes, four per side, spaced 0.8 inches apart. A circular opening in the top of the cell was provided for inserting the dielectric object(s) to be imaged. The fluid region measured 4 inches, by 4 inches, by 3 inches deep. Ordinary tap water was used as the conductive fluid. A test object, in this case a Plexiglas rod, is also shown being inserted into the test cell.

The function of the fluid within the test cell is two-fold. First, it conducts the current from the electrodes to the object being scanned. Second, it allows the transducer to be impedance matched to the background conductivity of the object being scanned. Impedance matching was not necessary in the test results reported here, since only the dielectric objects themselves were inserted into the test cell. However, in other applications where the dielectric is embedded in a conductive material, impedance matching could be accomplished by adjusting the salinity of the water.

Each of the sixteen electrodes was independently monitored by the A/D system and could be switched into one of three states: voltage high; voltage low, and voltage floating. A scan cycle consisted of successively placing each adjacent pair of electrodes in a high-low voltage state (one electrode high and the other low) while allowing the remaining 14 electrodes to float. There are 16 electrode pairs, with 16 voltage measurements per pair, yielding a total of 256 data points per scan. These data were then processed by the computer, converted to a grey-scale image, and displayed on the computer screen. All scan images reported below were taken directly from the computer display memory and printed exactly as they appeared when the test object was scanned.

Test Results

The tests described here were done in order to assess the capability of SCT to detect, locate, and differentiate between neighboring dielectric objects of various sizes. Of particular interest was determining the detection threshold for the system and its ability to track an object that was just above this threshold. Glass and Plexiglas rods of varying diameters were chosen as test objects. The rods were positioned within the test cell as shown in the cover photo, aligned parallel to the electrodes, and were completely inserted into the cell so that the end of the rod was at the cell bottom.

Figure 1 (Left) shows a scan image of a single, 0.205-inch diameter, circular glass rod. The scan image samples a 3.0-inch by 3.0-inch cross section of the fluid region, and is printed at approximately true scale. The rod was positioned near the cell center and appears on the scan at its actual position. Although there is some distortion from circular, its size (area) is approximately correct, being a little longer in one direction and shorter in the other.

Figure 1 (Right) shows a scan of two 0.205-inch diameter rods, separated by a 0.75-inch gap. The gap is defined as the closest distance between the outer surfaces of the two rods. The two rods are completely resolved in the image and the gap distance can be easily measured from the image to within a few percent of its actual value.

Figure 2 shows scan images of two, 0.33-inch diameter, circular Plexiglas rods. Two different gap distances are shown, 0.47-inch (Left) and 0.75-inch (Right), demonstrating the system's ability to distinguish changes in separation distance. Again, the gap can be measured from the image to within a few percent. As would be expected, the smaller gap spacing (Left) is not as sharp at the larger one (Right). Comparing Figure 2 (Right) with Figure 1 (Right), there is a remarkable degree of similarity, with the difference in rod diameter being accurately reflected in the images.

The detection threshold is a system dependent parameter, which is largely dependent upon signal to noise ratio. The smallest diameter rod which could be systematically detected and located by this system measured 0.08 inches in diameter. This represents 1/50 of the aperture of the device, which is 4.0 inches on a side. Figure 3 shows two scan images of the 0.08-inch diameter glass rod used to determine this threshold. Both the rod location and size can be easily measured from the scan images.

These results are very encouraging, given the simplicity of the transducer, the rather small number of electrodes, and the large electrode spacing. They further demonstrate that SCT has the capability to accurately detect and locate very small dielectric objects, to differentiate between neighboring objects, and to provide accurate spatial information, including separation distances and object sizes.

Potential Applications

Each potential application will present unique engineering requirements, relating to electrode configuration, conductivity matching, and contact coupling to the object being scanned. If immersion of the test object is not desirable, placement of the electrodes directly on the surface of the object could be considered. Also, materials that are considered a dielectric in one application might be considered a conductor in another, since many dielectrics have a finite (but, extremely small) conductivity. For example, highly purified water is used as a dielectric between metal conductors in high-voltage systems, but could be considered a conductor when compared to air, or a vacuum. It is the conductivity contrast which is important for successful SCT imaging and not the specific value of conductivity.

• Nondestructive Testing (NDT)

SCT has potential advantages over existing electrical imaging methods used in NDT. Eddy-current testing is an NDT method that utilizes a magnetic coil to induce electrical currents in a conductive material, usually a metal part. Limitations of eddy-current testing include: shallow penetration depth, useful only on high conductivity materials, and requires mechanical scanning to form an image. SCT is not limited to near surface defects, since current flows through the volume of the object. It is also applicable to a much wider range of background conductivity values and can form a cross-sectional image without mechanical scanning.

Other NDT applications of SCT could include real-time inspection of extrusion processes, provided the material being extruded has a finite conductivity. Sheet metal, metal films, and metal rods are obvious candidates for SCT. Other fluid flow processes in production facilities might also benefit from on-line SCT monitoring; e.g., the detection of gas evolution or cavitation.

• Biomedical Imaging

Parts of the human body having large conductivity contrasts would be particularly well suited to SCT imaging. Resistivity in mammalian tissue ranges from 1.5 $\Omega\cdot\text{m}$ (blood), 4.5 $\Omega\cdot\text{m}$ (liver), 25.0 $\Omega\cdot\text{m}$ (fat), to 166 $\Omega\cdot\text{m}$ (bone). An SCT image of a forearm, for example, would allow precise identification of regions of bone, ligament, muscle, fat, etc. Interventional radiologists could also use SCT for guiding the placement of appliances during corrective procedures, since parts made from plastics or metals have much different conductivity properties than the tissue into which they are being inserted.

Although medical researchers have been working to develop a useful Electrical Impedance Tomography (EIT) system since the early 1980's, image quality has been poor in the few experimental systems that have been tested to date¹. The experimental results reported here demonstrate a marked improvement in resolution of SCT over prior EIT systems.

• Geophysics

Electrical methods have long been used in geophysical prospecting, since at least 1930, due to the large variation in electrical properties of rocks. Water content of rocks and soils also has a dramatic effect on conductivity, as does the addition of any other fluid conductor. Underground contamination from chemical leaks, or other hazardous waste, could have a dramatic effect on soil conductivity and should therefore be well suited to SCT imaging.

¹D. C. Barber, Clin. Phys. Physiol. Meas., 1990, vol. 11, 45-56.

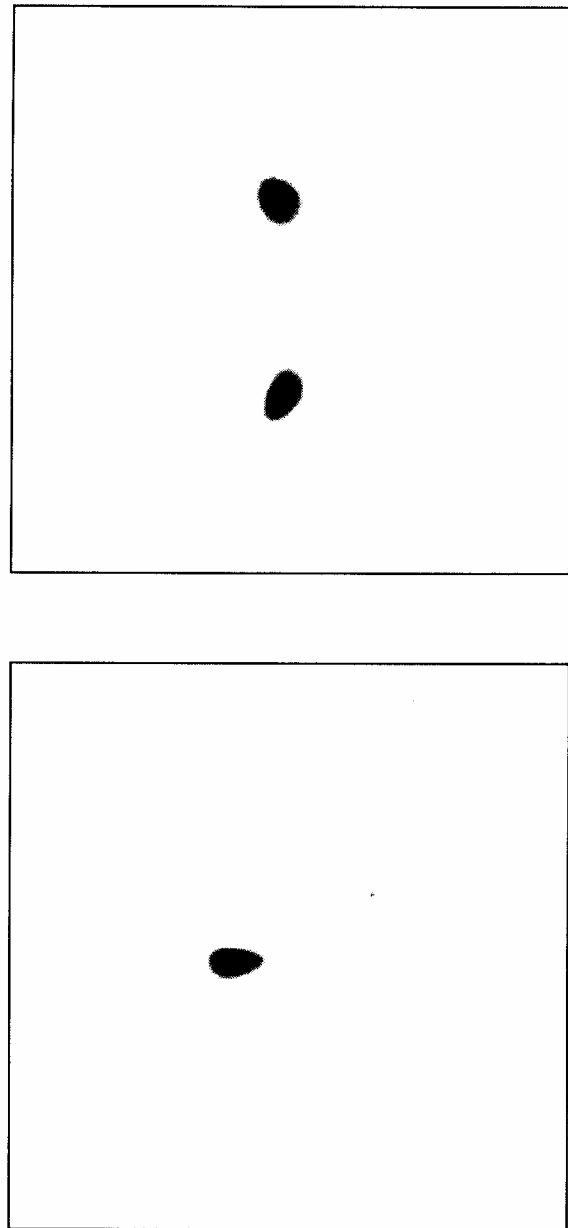


Figure 1. SCT scans of 0.205-inch diameter, circular glass rod(s).
(Left) Scan of a single rod, placed near the center of the test cell.
(Right) Scan of two rods, separated by a 0.75-inch gap. Although the rods appear slightly distorted from circular, their size appears approximately correct. The gap separation is very well determined from the image.

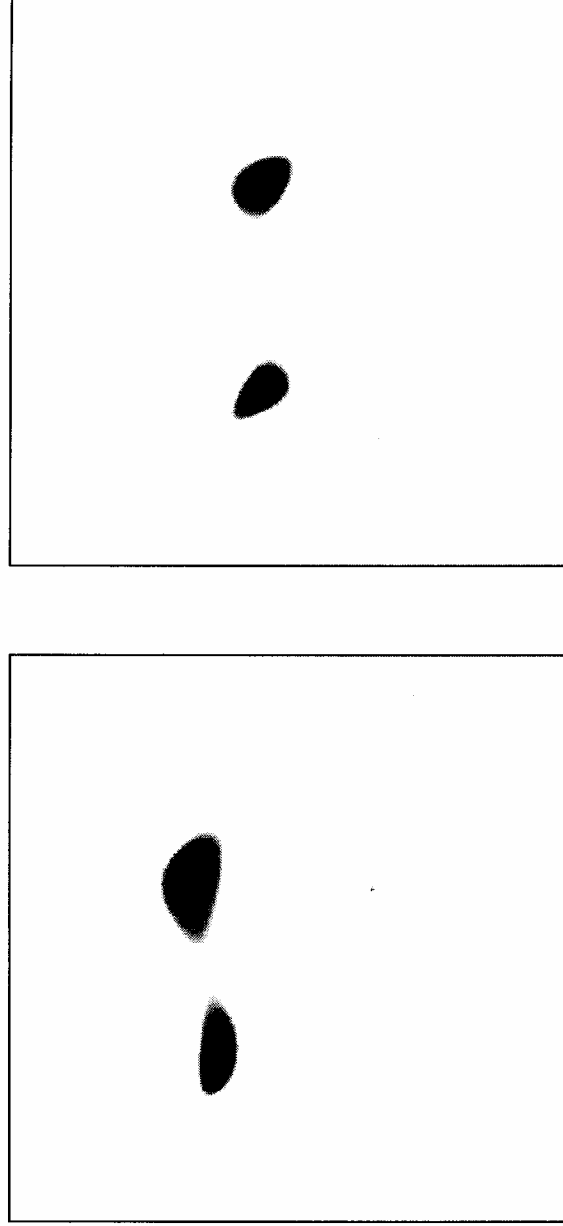


Figure 2. SCT scans of two, 0.330-inch diameter, circular Plexiglas rods. (Left) Gap separation of 0.47 inches. (Right) Gap separation of 0.75 inches. These images clearly reflect the number of rods and the actual gap sizes. Comparison with Figure 1 shows that the increase in rod diameter is also accurately reflected in these images.

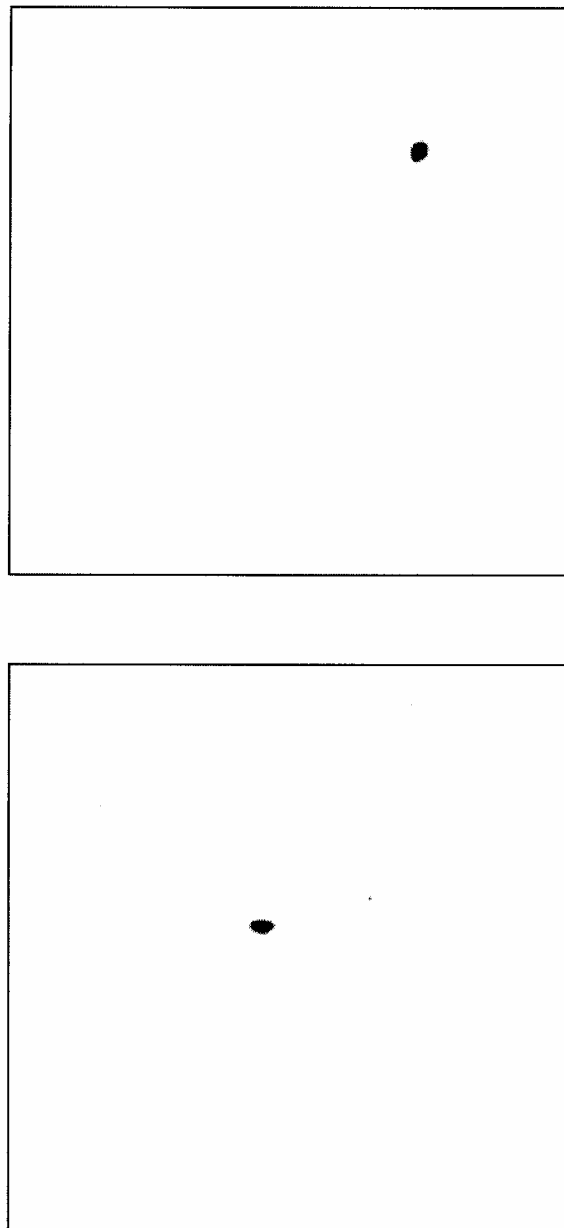


Figure 3. SCT scans of a single 0.08-inch diameter, circular glass rod. (Left) Rod located near the cell center. (Right) Rod located in lower right-hand quadrant of the test cell. Both rod diameter and location are accurately determined from the scan images. These scans demonstrate the ability of SCT to detect and locate very small objects.